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14. ABSTRACT

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discussion of the three current Air Force UAV Systems (Predator, DarkStar, and Global Hawk) followed by some proposed methods and procedures for rendezvous and aerial refueling of these UAV platforms. The author rounds out his discussion by comparing and analyzing both the current UAV systems and the methods of air refueling. After proposing the UAV system best suited for air refueling, the most effective type of rendezvous for this UAV system, and the best method for controlling the UAV during the air refueling, the author concludes with a brief review of the implications for the Air Force and airpower enthusiasts.

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THE AIR REFUELING RECEIVER THAT DOES NOT COMPLAIN

BY

JEFFREY L. STEPHENSON

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Disclaimer

The conclusions and opinions expressed in this document are those of the author. They do not reflect the official position of the US Government, Department of Defense, the United States Air Force, or Air University.

About The Author

Major Jeffrey L. Stephenson was commissioned through Officer Training School in 1985. Following graduation, he was assigned to Robins Air Force Base as a KC-135 A/R pilot. Subsequent to this, he was an instructor pilot/evaluator pilot in the KC-135R and a CCTS instructor in the KC-135R. In Major Stephenson's most recent assignment, he was a CFIC instructor/evaluator pilot training KC-135 instructor pilots throughout all the Air Force commands. Major Stephenson holds a bachelor's degree in Chemistry from the University of Mississippi and a master's degree in Aerospace Operations/Management from Embry-Riddle Aeronautical University. In June 1998, he was assigned to US Transportation Command (TRANSCOM) as a member of the CINC's Action Group (CAG).

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Most importantly, I want to express my sincere gratitude and love to my wife, Tina, my son, Gregory, and my daughter, Michelle, for their patience and understanding during those many times when I put the completion of this study ahead of much more important interests.

Abstract

This study focuses on the development of aerial refueling methods and procedures for unmanned aerial vehicles (UAVs). The author begins this work by stating the need for UAVs, lists some assumptions, and then gives a brief background on UAVs. The author then begins a thorough discussion of the three current Air Force UAV Systems (Predator, DarkStar, and Global Hawk) followed by some proposed methods and procedures for rendezvous and aerial refueling of these UAV platforms. The author rounds out his discussion by comparing and analyzing both the current UAV systems and the methods of air refueling. After proposing the UAV system best suited for air refueling, the most effective type of rendezvous for this UAV system, and the best method for controlling the UAV during the air refueling, the author concludes with a brief review of the implications for the Air Force and airpower enthusiasts.

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Chapter 1

Introduction

> *Current national, theater, and tactical intelligence assets are insufficient to provide for urgently needed, critical, worldwide, releasable near real time intelligence on fixed and mobile targets for the in-theater Commander-in-Chief (CINC), Joint Forces Commander (JFC), and the National Command Authority.*
>
> —*-USD (A&T) Memorandum, 12 July 1993*

Almost since the beginning of time, man has found it necessary to settle his disputes through armed conflict. These armed conflicts have fallen along the spectrum of conflict anywhere from limited war to total war. Additionally, we have been faced with situations ranging from peacekeeping to a Cold War. These conflicts and situations have a common thread that links them together, one must potentially render more punishment against the adversary than he can deliver against you. The United States is no different and since World War I (WWI) it has tried to find ways to eliminate or minimize American loss of life or "punishment" during conflicts. One of the ways the U.S. can take its forces out of harm's way is through the use of Unmanned Aerial Vehicles (UAV).

UAVs have been used to support military reconnaissance needs since WWI. "Historically, most UAVs have been very small, some even hand-launched like toy radio-

controlled airplanes, and mostly confined to the reconnaissance role."[1] However, times have changed as have the UAVs and the demands placed upon the UAV platforms and the Air Force. The Air Force finds itself in a period of military cutbacks and further burdened by resource shortages; yet the number of missions and taskings are increasing. This puts the United States Air Force in a position where it must be more creative in order to do more with less. Partly as a result of this situation, UAVs are much larger in size, more technologically advanced, tasked to perform long endurance reconnaissance missions, and may be called upon in the future to perform missions such as interdiction and SEAD (suppression of enemy air defenses) missions previously reserved for manned platforms only. Representative Randy "Duke" Cunningham (R-California) stated the following about the Global Hawk UAV, "Why do we need this system? Because technology like this will enhance national security and save lives."

In order to perform these long duration missions, the U.S. must devise methods to enable UAVs to loiter over the theater of operations for extended periods of time. One answer to these long duration missions is to deploy UAVs to forward bases of operation. By deploying UAVs to forward bases, the UAVs would be closer to the theater of operations, thus decreasing their en-route time and increasing their loiter time. However, forward basing options are dwindling quickly in this time of base relocations and closures, not to mention military budget cuts. Furthermore, forward basing tensions will increase in the future due to political instability overseas and shifting foreign relations with our "allies."

[1] Maj Christopher A. Jones, USAF, "Unmanned Aerial Vehicles (UAVS): An Assessment of Historical Operation and Future Possibilities," ACSC Research Paper, (March 1997): 8.

A second answer to long duration missions is to simply build larger UAVs. Larger UAVs are technologically feasible, but the larger the UAV, the more expensive it is to build and the more vulnerable it becomes to hostile fire. The current impetus for building UAVs is to manufacture a platform that is both economical and has a small radar cross section (RCS); yet can perform the same missions as the manned platforms that the Air Force currently employs. However, by building larger UAVs, the Air Force would violate both of the principles above: driving up the cost of each UAV and increasing the RCS.

A third option is to purchase large numbers of the UAVs. This option would allow the profiles of the UAVs to overlap and with a positive mission hand-off no lapse in coverage would occur. However, as the number of UAVs increase so will the total purchase cost, the maintenance cost, and the support cost to maintain such a large fleet in combat readiness status.

Perhaps the best solution to the UAV endurance problem is to simply make the UAVs air refuelable. The United States Air Force has the largest tanker force in the world. By incorporating or designing an air refuelable system into the current Air Force UAVs, the need to build larger UAVs, to buy more UAVs, or to maintain forward basing is negated. Although the Air Force has no current UAV systems that are air refuelable, the idea does bring to mind an interesting question: How should the Air Force approach unmanned aerial vehicle air-to-air refueling today? This research thesis will endeavor to answer this question. Chapter 2 will describe the need for making UAVs air refuelable. Discussion will include what options air refuelable UAVs will open up to the Air Force to include: trading off range for payload, decreasing the number of UAVs required in the

theater of operations, and performing intelligence, surveillance, and reconnaissance (ISR) missions in place of manned platforms. Furthermore, chapter 2 will discuss the current Air Force UAV systems—Predator, Darkstar, and Global Hawk. Chapter 3 will outline three methods for air refueling rendezvous' including: point-parallel, overtaking point point-parallel, and enroute. Furthermore, several alternatives will be proposed for controlling the UAV from rendezvous completion to the end of air refueling. Chapter 4 will compare and contrast the three current Air Force UAV systems as well as the alternatives for rendezvous and air refueling. Chapter 5 will present some conclusions and implications for the United States Air Force from the research.

Assumptions

Several assumptions will be made in order to narrow the scope and focus of this thesis. First, this paper is limited to current Air Force UAV systems. The term "current Air Force" in this context means only those systems fielded by or on the drawing board for the Air Force at this time. Second, the only UAV systems considered will be those possessing, as a minimum, the following performance capabilities: 8 hour flight duration, flight altitudes greater than or equal to 25,000 feet Mean Sea Level (MSL), and payloads in excess of 500 pounds (including both internal and external payloads). Third, there will be no change in Air Force missions in the next few years. Fourth, there will be no increase in Air Force budgets.

Background

UAVs are not new to aviation by any stretch of the imagination. Pilotless aircraft, whether used for aerial target purposes or for more belligerent purposes, have a history

stretching back as far as WWI. *Jane's All the World's Aircraft*, an annual definitive guide to aerial platforms and weapons, describes UAVs and their uses as far back as the 1920s.[2] However, the event which brought the need for UAVs to the forefront was the downing of Francis Gary Powers' U-2 spy plane over the Soviet Union on 1 May 1960.[3]

President Dwight D. Eisenhower authorized the development of long-range U-2 reconnaissance aircraft by Lockheed in 1954. Eisenhower hoped to persuade the Soviet leader Nikita Kruschchev to adopt an "open skies" policy of mutual aerial surveillance. The President hoped the "open skies" policy would serve as a deterrent to surprise attacks and reduce tensions between the United States and Russia. However, Krushchev rejected Eisenhower's proposal and within a few months the President authorized overflight of Russian territory by U-2 aircraft to photograph Soviet missile development and deployment activities.

Powers' intended route of flight was to take him from Pakistan to Norway to photograph the Soviet's Tyuratam missile test facility. When Powers did not show up in Norway, U.S. officials developed a cover-up story stating on 2 May 1960 that a National Aeronautics and Space Administration (NASA) aircraft was missing after a routine weather reconnaissance flight over Turkey. Shortly after this announcement, Krushchev announced on 5 May that Russia had shot down a U.S. aircraft. On 6 May 1960, NASA modified its story now stating the aircraft was a U-2 on a high-altitude research flight. Furthermore, the pilot was a Lockheed civilian employee who had drifted off course into Soviet airspace after reportedly having trouble with his oxygen equipment. The cover-up

[2] Kenneth Munson, *Jane's Unmanned Aerial Vehicles and Targets*, (Surrey, UK: Jane's Information Group Limited, 1996).

story was blown wide open when Krushchev announced on 7 May 1960 that the pilot was alive and imprisoned in Moscow; and the pilot had confessed to flying a spy mission over the heart of the Soviet Union.

The shoot-down of Powers dealt a devastating blow to the international prestige of the United States. Although Eisenhower accepted full blame for the incident, the country became extremely sensitive to manned reconnaissance. Having promised to discontinue all U-2 flights into Soviet airspace, the U.S. had to find a way to fill the gap in the intelligence coverage of the Soviet Union. Consequently the U.S. increased the development of satellite reconnaissance systems, the SR-71, and reconnaissance drones. However, satellite based photography from the much higher altitudes could not provide the one foot high-resolution photography previously provided by the airborne collectors.[4]

Despite the urgings of high-level Pentagon officials to fund the development of UAVs, neither DOD nor the CIA would provide any significant funding.[5] As a result, the support for unmanned reconnaissance drones quickly subsided within the U.S. military. For example, the Ryan Aeronautical Company's first development effort, code-named *Project Red Wagon*, was terminated by the Air Force in late 1960. Evidence discovered later pointed to the development of the SR-71 and spy satellite programs (CORONA) as the cause for the demise of *Project Red Wagon*.

Just two short years later, the shoot-down of another U-2 aircraft overflying Cuba on 27 October 1962 brought the issue of reconnaissance drones back into the limelight. A Soviet SAM, protecting a ballistic missile site, destroyed the aircraft and killed the

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[3] William Wagner, *Lightning Bugs and Other Reconnaissance Drones* (Fallbrook, CA: Aero Publishers, 1982) 1.
[4] Ibid., 1-4.

pilot. The nation was outraged and the public outcry for unmanned reconnaissance grew louder. Classified work on the D-21 Tagboard and the AQM-34 Lightning Bug (figure 1) began shortly after the second shoot-down.

Figure 1: AQM-34 Lightning Bug

The Air Force decided to develop a new reconnaissance system based upon a target drone airframe (the BQM-34).[6] Not only had the Cuban situation highlighted the need for near real-time intelligence gathering but it also rekindled the political sensitivity of using manned collection platforms. As the U.S. involvement in Vietnam continued to increase, the Air Force fielded its first operational photo-reconnaissance unmanned aircraft, the Ryan Aeronautical "Lightning Bug" (the AQM-34).

Throughout the course of the Vietnam War the capabilities of the Lightning Bug evolved to support other missions beyond photographic missions. These missions provided a showcase of the future potential capabilities for UAVs. Modifications in the Lightning Bug supported: real-time video, electronic intelligence (ELINT), electronic counter measures (ECM), real-time communications intelligence (COMINT), and PSYOPS leaflet dropping. UAVs even conducted low altitude missions, providing

[5] Ibid., 19.
[6] Ibid., 23.

critical battle damage assessment (BDA) against key targets. However, the interest in reconnaissance UAVs decreased as the Vietnam War drew to a close.

The interest in UAVs remained dormant for the Air Force until Operations Desert Shield and Desert Storm. Combat operations in Libya and Grenada identified the need for inexpensive, unmanned, reconnaissance capabilities for commanders. Because of these operations, the Navy started the Pioneer program in the late 1980s. "By the time Iraq invaded Kuwait in 1990, the Navy, Marine Corps, and Army operated UAVs. With 85% of the United States' manned tactical reconnaissance assets committed, UAVs emerged as a 'must have' capability."[7] UAVs provided near real-time reconnaissance, surveillance, and target acquisition (RSTA) and BDA around the clock during Operations Desert Storm and Desert Shield. Additionally, UAVs worked with the Joint Surveillance and Target Attack Radar System (JSTARS) to confirm high priority mobile targets.[8]

Currently, the Department of Defense (DOD) is developing two classes of UAVs in support of *Joint Vision 2010*—tactical and high-altitude endurance UAVs. All three of the Air Force's current UAV programs are utilizing a fast-paced acquisition strategy known as Advance Concept Technology Demonstration (ACTD). The tactical class consist of the Tier II Medium-Altitude Endurance UAV (Predator). The tactical class of UAVs are assets, controlled at tactical echelons, and provide coverage focused close to the forward line of troops (FLOT). Tactical UAVs can provide such information as the position of enemy troops, vehicles, and artillery. The two high-altitude endurance (HAE) UAVs, Tier II Plus (Global Hawk) and Tier III Minus (Dark Star), will be theater-level assets and provide deep, long endurance, broad area surveillance in the theater of operations. The HAE UAVs will provide valuable information such as the movement and positioning of enemy reserve forces as well as imagery and electronic intelligence on strategic targets deep within enemy territory.

"The move to UAVs is being driven by two primary factors: the American public has become increasingly intolerant of warfare casualties, and the nature of warfare is

[7] Jones, 5.

[8] Office of the Under Secretary of Defense (Acquisition & Technology) (OUSD(A&T)), *Annual Report: Unmanned Aerial Vehicles (UAVs)* (Washington, D.C.: Defense Airborne Reconnaissance Office (DARO), August, 1995.

changing."[9] The commander in the field cannot afford to lose any of his limited and valuable resources, thus the need for more real-time information is growing. Often, the enemy is not conventional military forces, but they are terrorists, guerillas, or other small groups. Before military forces can be brought to bear against these adversaries, the enemy must be located, identified and subdued with surgical precision—missions for which UAV capabilities are well suited. Due to the decreasing number of forward staging bases, international political tension, large numbers of commitments, and instability caused by positioning military forces in foreign nations, a solution must be found to provide the information necessary to protect America's vital interests. One sure means to acquire this vital information is with large numbers of "cheap" long-endurance UAVs. However, the only way to ensure UAVs can loiter in the area of operations a sufficient amount of time and in sufficient numbers to accomplish these missions is with air-to-air refueling capability.

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[9] *Highs and Lows*, Lockheed Martin, n.p.; on-line, Internet, 22 October 1997, available from http://www.lmco.com/lmtoday/0496/darkstar.html

Chapter 2

The Need for Air Refueling UAVs and Current AF Systems

> *As an old fighter pilot, I have a saying that says one peek is worth a thousand sweeps. That means if you can get your eyeball on the target, that's worth a thousand sweeps of your radar, and that is what (Global Hawk) promises to give us…visibility into what's going on across the battlefield so our forces can have that precious commodity we call situational awareness. (With it) you can integrate your forces in a way that takes advantage of the synergies across all our weapons systems…with a minimum loss of life.*
>
> *--General Richard E. Hawley, USAF, Commander, Air Combat Command*

The improvements in flight and microelectronic technology over the past twenty years have made the design and production of long endurance UAVs feasible. With the long endurance capability of current UAVs, the question raised becomes: why do we need to make UAVs air refueling capable? First, as General Hawley pointed out, UAVs have the capability to visually observe the target without a manned aircraft being in radar range of the target or even in the theater of operations. Making UAVs air refuelable would double or triple the loiter time, allowing a single UAV to perform the missions of two or three unrefuelable UAVs. The end result is a reduced "foot print" of American presence, a significant decrease in production and maintenance costs, and a large logistics support cost savings.

Second, UAVs are now able to perform many of the intelligence, surveillance, and reconnaissance (ISR) missions previously reserved for manned platforms. Air refuelable UAVs could perform these missions without taking into account the limitations associated with crew rest and crew duty day; problems that must be dealt with when crewmembers are required on-board for systems operations. Additionally, UAVs can perform more dangerous or risky missions than manned flights because of the reduction in the chance for loss of life.

The UAV could extend the duration of its mission by air refueling and returning to the target area without a lapse in coverage, allowing the manned platforms to perform missions of higher priority where the risk demands the use of a several hundred million dollar airframes. The substitution of refuelable UAVs for manned platforms could negate the current requirements for large numbers of the more expensive aircraft, saving tremendous amounts of money on aircraft modifications, not to mention the associated costs for organizing, training, and equipping additional aircrew members.

The third reason for making UAVs air refuelable is to tradeoff range for payload. Current Air Force UAVs systems have tremendous endurance capabilities with mission durations ranging from 24 hours up to approximately 40 hours. However, the missions these UAVs perform are limited by the equipment carried on board. If a portion of the fuel tank system were removed, the number of sensors be increased making the UAV a more capable system, a specialized system tailored to a specific mission, or additional systems (such as weapons) could be added on since we can always refuel the UAV at a later time. The bottom line is highly capable refuelable UAVs would give both an

increase in mission performance and mission duration while realizing tremendous savings in production, maintenance, and modification programs.

Classification of UAVs

UAVs are grouped into several operational categories: endurance and range (maneuver, tactical, and medium). The endurance category of UAVs describes a class of aerial vehicles operating at medium and high altitudes, carrying payloads with multi-mission performance capabilities, on-demand support across all mission areas, and duration of flight normally in excess of 24 hours. All three current Air Force UAV systems, the *Predator* Medium Altitude Endurance (MAE), *Global Hawk* High Altitude Endurance (HAE), and *DarkStar* Low Observable High Altitude Endurance (LO-HAE), all fall under the endurance UAV category and will be discussed in detail later in this chapter.

In order to further clarify the classification of UAVs, tier numbers and an altitude designators are assigned to each UAV system. The Tier number associated with the UAV, for example *Global Hawk* (Tier II+), simply identifies the generation of the UAV. *DarkStar* is the latest generation UAV and is designated a Tier III- UAV. The altitude designators, medium and high, define the operating altitude capability of the UAV. Medium altitude UAVs are those capable of operating at altitudes no greater than 25,000 feet MSL. High altitude UAVs are those capable of operating at altitudes in excess of 25,000 feet MSL.

Predator

The *Predator* UAV (Figure 2) was DOD's solution to an intelligence collection shortfall encountered during the Persian Gulf conflict. This need is clearly outlined in a memorandum from the Under Secretary of Defense (Acquisition and Technology)(USD (A&T)).

> *"Current national, theater, and tactical intelligence collection assets are insufficient to provide for urgently needed, critical, worldwide, releasable near real time intelligence on fixed and mobile targets for the in-theater Commander-in-Chief (CINC), Joint Forces Commander (JFC), and the National Command Authority (NCA). No system exists which can provide continuous all-weather coverage of small mobile or fixed targets. Existing theater airborne assets are limited by endurance of less than 8-12 hours, limited numbers, and possible loss of air crew over hostile areas. Ground based systems cannot operate in denied and/or hostile areas without the possibility of loss/capture of personnel."*[10]

Theater CINCs and Joint Task Force (JTF) commanders demanded intelligence collection assets that could provide near-real time (NRT) information, continuous coverage, and interoperability with command, control, communications, computers, and intelligence (C4I) structures without endangering human life or sensitive technologies. The MAE or Tier II UAV, *Predator*, is a derivative of the Gnat 750 (Tier I) UAV currently used by the Central Intelligence Agency (CIA). "The system provides long-range, long-dwell, near-real-time imagery intelligence (IMINT) to satisfy reconnaissance, surveillance and target acquisition (RSTA) mission requirements."[11]

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[10] Under Secretary of Defense for Acquisition and Technology (USD(A&T)) Memorandum, 12 July 1993.

[11] Office of the Under Secretary of Defense (Acquisition & Technology) (OUSD(A&T)), *UAV Annual Report FY 1997* (Washington, D.C.: Defense Airborne Reconnaissance Office (DARO), 6 November 1997), 30.

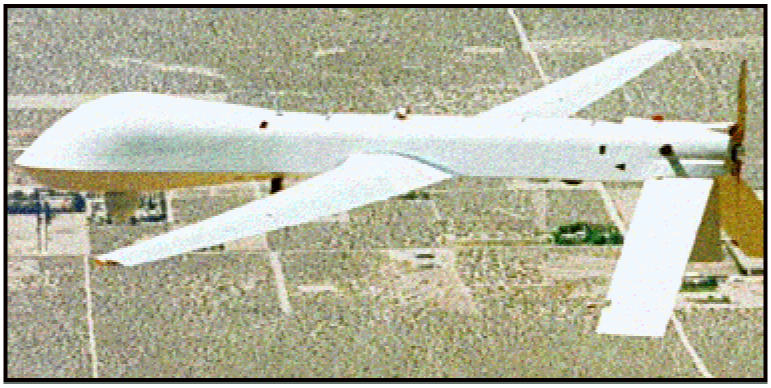


Figure 2: *Predator* Tactical UAV

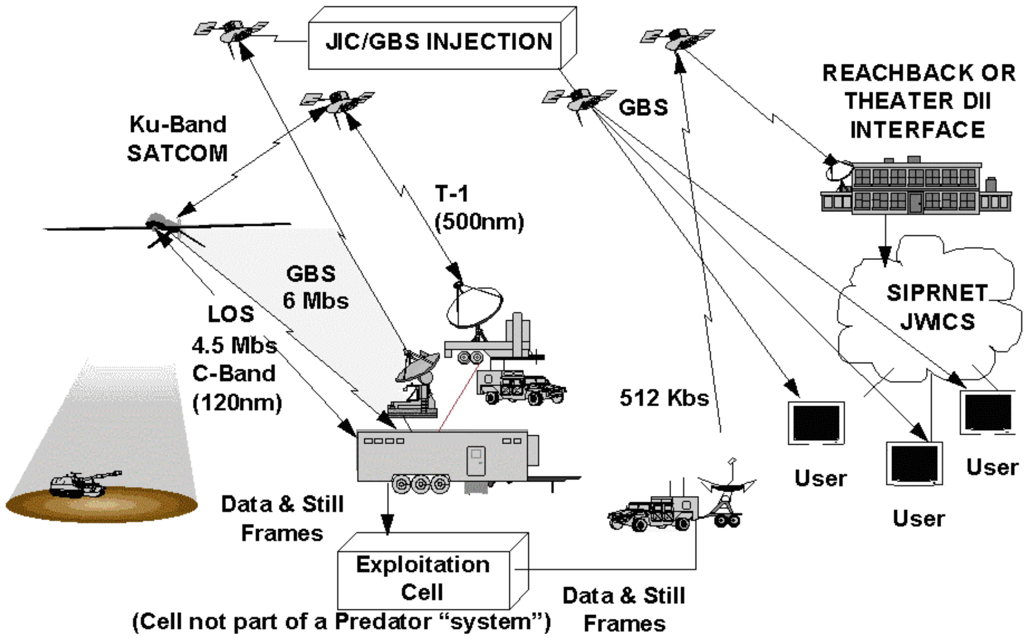
The *Predator* system consists of three parts: the air vehicle (with its associated communication equipment and sensors), the ground control station (GCS), and the data dissemination system. The air vehicle carries electro-optical (EO, both still frame and video), infrared (IR, still frame), and synthetic aperture radar (SAR, still frame). The EO, IR, and SAR sensors used with a Ku-band satellite communication (SATCOM) link, enable the system to acquire as well as pass highly accurate imagery to the ground control station (GCS) for theater-wide use by the tactical commanders (see Table 1). The field commander is able to dynamically re-task the sensors by a command link to the air vehicle from the ground station.

Table 1: *Predator* UAV System Characteristics

Cost	$3.2M per vehicle (with EO/IR/SAR), $2.2M for Trojan Spirit, $2.9M for Ground Control Station
Dimensions	Wingspan - 48.7 ft.; Length - 26.7 ft. ; Height – 7.3 ft.
Weight	Max. Gross Weight - 2,500 lb. (includes 660 lb. fuel); >1873 lbs. (EO/IR)

Runway Requirement	2,500 ft.
Payload	>450 lbs.
Operational Radius	500 NM
Duration	24+ hr. on station, total mission duration up to 40+ hrs.
Airspeed	60 - 110 knots; cruise @ 70 knots TAS
Altitude	Max. Ceiling - 25,000 ft. MSL
Flight Control	Manual take-off/landing, fully autonomous or remotely piloted, dynamically re-tasked in flight
Survivability	No ECM or low observable technologies
Deployment	Ten C-130s, Six C-141s, Two C-5/17 for equipment only, operational six hours after arrival on site
C2 Link	UHF MILSATCOM (16 KBs), Ku-band commercial (1.5 MBs), LOS (4.5 MBs)
Sensors	simultaneous EO/IR (0.5 ft. resolution) and SAR (1.0 ft resolution) capable; SAR only via Ku-band or LOS
Total System	4 Air Vehicles, 4 Modular Mission Payloads, 1 Ground Control Station (GCS), 1 Remote Video Receiving Station, Launch & Recovery and Ground Support Equipment

A complete package or subsystem, to maintain continuous 24 hour coverage, consists of four air vehicles, one ground control station, sensor payloads, data links, ground support equipment, and trained personnel. The air vehicles contain “commercial off-the-shelf” (COTS) sensor hardware; this is significant because sensitive technology will not be lost if the air vehicle is lost over hostile territory. The recent addition of de-icing equipment allows the air vehicle to operate in and transit adverse weather conditions. The GCS consists of the following personnel: a pilot, a payload operator, two data exploitation and communications operators, and 28 other support positions. Data from the sensors aboard the *Predator* vehicle integrate into the current theater-level C4I architectures via the TROJAN SPIRIT II (TS II) SATCOM system (Figure 3).

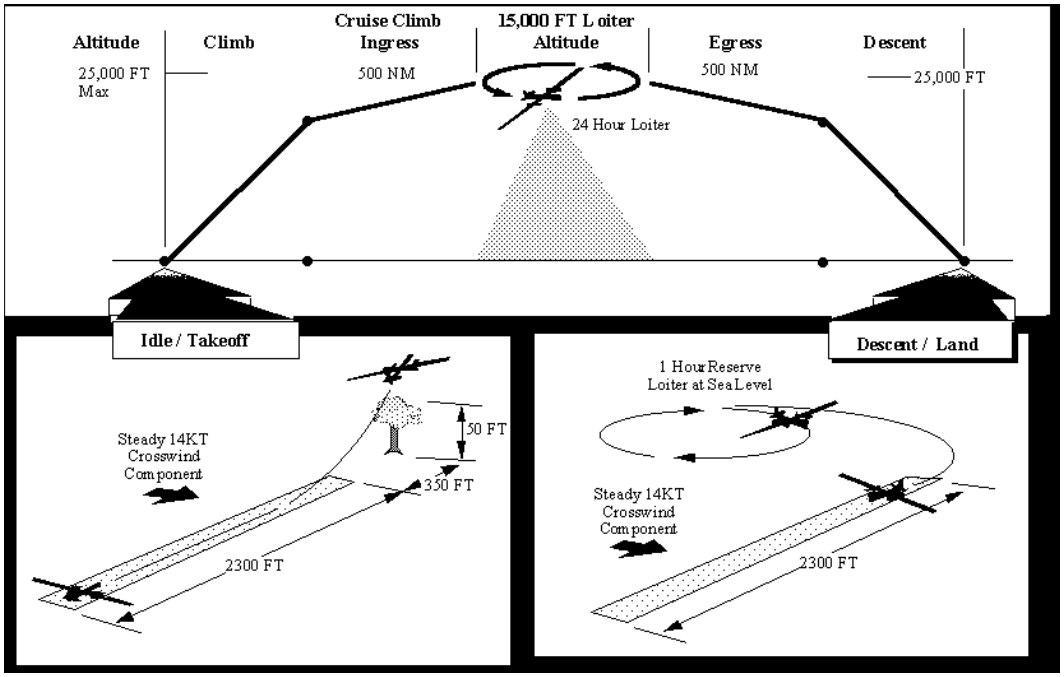


Source: Extracted from the ACC Endurance UAV CONOPS, 3 December 1996—Version 2

Figure 3: Notional *Predator* Mission Concept

In order to provide near-real time broadcast of video imaging to theater and national users simultaneously, the dissemination system uses either the Joint Broadcast System (JBS) or the TS II, or both.

The mission profile of the *Predator* UAV is found in Figure 4. The aerial vehicle is quite capable, withstanding up to a 6G maximum loading on the wing structure, and integrates a Mode 3 transponder into the onboard avionics package for altitude and position reporting. Once the *Predator* reaches its loiter altitude and position, the EO and IR video data is passed via line-of-sight (LOS) or UHF/Ku-band Satellite data link to the GCS. SAR framed imagery requires Ku-band to transmit data to the GCS that is passed to the GCS via a satellite link.



Source: Extracted from the ACC Endurance UAV CONOPS, 3 December 1996—Version 2

Figure 4: *Predator* (Tier II) Mission Profile

Although the *Predator* is a very capable system, the later generation UAVs, *Global Hawk* and *DarkStar*, are much more capable systems.

Common Ground Segment – High Altitude Endurance UAVs

The *DarkStar* and *Global Hawk* UAVs in conjunction with the Common Ground Segment (CGS) form the HAE UAV system. The CGS controls the aerial vehicles (AVs) and ensures interoperability between the AVs and transmission of sensor data to the C4I infrastructure. The CGS consists of a Launch and Recovery Element (LRE), a Mission Control Element (MCE), a *DarkStar* Data Processing Element (DS DPE), and associated maintenance, communications, and support elements. The LRE is responsible for preparing, launching, and recovering the aerial vehicles. The MCE plans and executes

the mission, processes and stores/disseminates imaging and ground moving target indicator (MTI) data, and dynamically re-tasks the AV and its sensors.

The HAE CGS is capable of controlling up to three HAE UAVs at one time. By using line-of-sight data links or satellite communication relays, the CGS enables a single system to maintain a continuous presence for many days at extended ranges from the operating station. The AVs transmit digital imagery to the MCE via wide band LOS or satellite links for initial processing and relay to the theater of operations. This data may also be relayed to continental United States (CONUS) imagery exploitation systems (IES) using standard (CIGSS-compliant) formats.

The desired imagery and reports will be able to be broadcast directly to tactical commanders, giving them the current battlefield picture. When the system is linked with such systems as the Global Command and Control System (GCCS) and the Joint Deployable Intelligence Support System (JDISS), the unexploited digital imagery will be transferred to the operational commander in near-real-time for immediate use. "Thus, the HAE CGS will provide digital, high-quality imagery to warfighters and users at various command levels."[12]

DarkStar

DarkStar, formerly identified as a Low Observable High Altitude Endurance (LO HAE) or Tier III- UAV, is designed to operate in highly defended areas and provide critical imagery intelligence (Figure 5). *DarkStar* uses low observable technology to minimize the air vehicle's detectability, trading air vehicle performance and payload capacity for survivability features against enemy air defenses.

Figure 5: *DarkStar* UAV

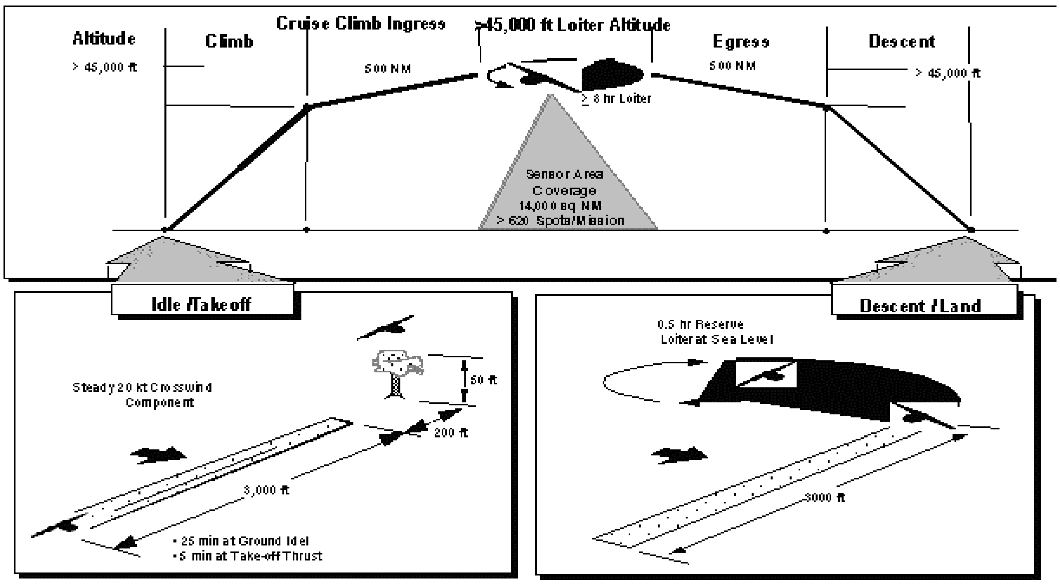
The payload of the AV is either SAR or EO sensors. The *DarkStar* UAV system characteristics are listed in Table 2 below. One unique characteristic of the *DarkStar* UAV is its ability to radiate a SAR sensor and still maintain its stealthiness. This is possible due to the many reasons: the SAR sensor uses low power, low probability of intercept (LPI) waveform of the signal, and a low AV radar cross section (RCS) sidelobe suppression antenna. While operating in the search mode, the SAR will provide strip images about 5.6 NM wide. However, coverage is limited because both the EO and SAR sensors only look off the left side of the aerial vehicle.

[12] Ibid., 35.

Table 2: *DarkStar* UAV Characteristics

Cost	$10M per vehicle (with EO/IR/SAR), $20M Ground Control Segment
Dimensions	Wingspan – 69 ft.; Length – 15 ft.; Height – 3.5 ft.
Weight	Max. Gross Weight – 8,600 lbs. (includes 3,240 lbs. of fuel)
Runway Requirements	5,000 ft., automatic take-off and (with differential GPS) landing
Payload	1,000 lbs. SAR; 800 lbs. EO
Operational Radius	500 NM
Duration	>8 hours on station, total mission duration up to 12 hours
Airspeed	>250 knots TAS
Altitude	>45,000 ft.
Flight Control	Vehicle can taxi, take-off, climb, cruise, descend, and land fully autonomously using differential global positioning system (DGPS), dynamically re-tasked in flight
Survivability	Very low observable
Deployment	3 C-141s or Multiple C-130s
C2 Link	UHF MIL SATCOM (16 KBs), Ku-band commercial (1.5 Mbps), LOS: X-Band Wide band (CDLS) (137-275 Mbps)
Sensors	EO (NIIRS 6) or SAR (1 m. search and 0.3 m. spot); capable of 14,000 sq. NM or 620 spot images/8 hr. mission with 20 m CEP accuracy

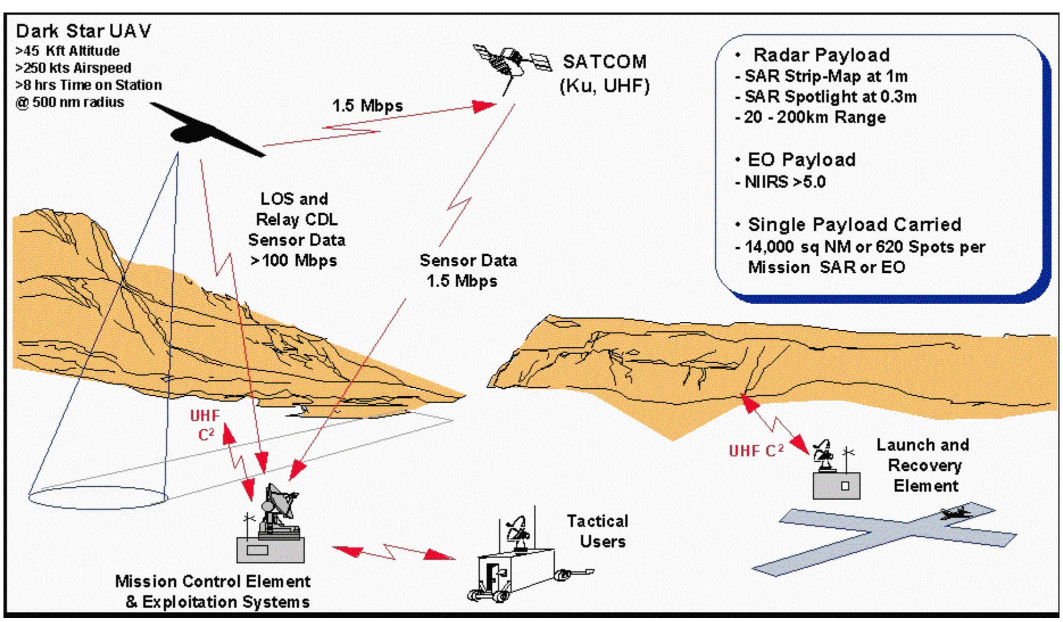
The notional mission profile of the *DarkStar* UAV is found in Figure 6 below. The *DarkStar* UAV will takeoff and climb to an altitude greater than 45,000 feet MSL and then cruise to its loiter position; once in position, the onboard sensors will begin to transmit data.



Source: Extracted from the ACC Endurance UAV CONOPS, 3 December 1996—Version 2

Figure 6: Notional *DarkStar* (Tier III-) Mission Profile

The objective is to have untethered worldwide operations, sending sensor data via satellite link from the aircraft to the MCE. *DarkStar*'s Ku-SATCOM normally transmits data at 1.5 Mbps, however, data rates up to greater than 100 Mbps are envisioned as achievable when using commercial satellites (e.g., PANAMSAT and INTELSAT).



Source: Extracted from the ACC Endurance UAV CONOPS, 3 December 1996—Version 2

Figure 7: Notional *DarkStar* Split-Site Concept

A second method of providing data to the MCE, when the UAV is operating within LOS, is through the common data link (CDL)(see Figure 7 for *DarkStar* Split-Site Concept). Either via satellite or CDL, *DarkStar* provides data to the MCE for processing and then the MCE retransmits processed/compressed data to the theater and/or national sites for intelligence exploitation.

In the future, it is hoped that *DarkStar* will be able to have a data link directly from the AV to the theater exploitation site. However, this concept depends upon on-board processing capability and a low observable data link antenna, the feasibility of which is yet to be determined.

Global Hawk HAE UAV

Figure 8: *Global Hawk* UAV

Global Hawk (Figure 8), previously referred to as the Conventional High Altitude Endurance (Conv HAE) or Tier II+ UAV, will be the HAE UAV "workhorse" for missions requiring long-range deployment and wide-area surveillance or long sensor dwell over the target area.

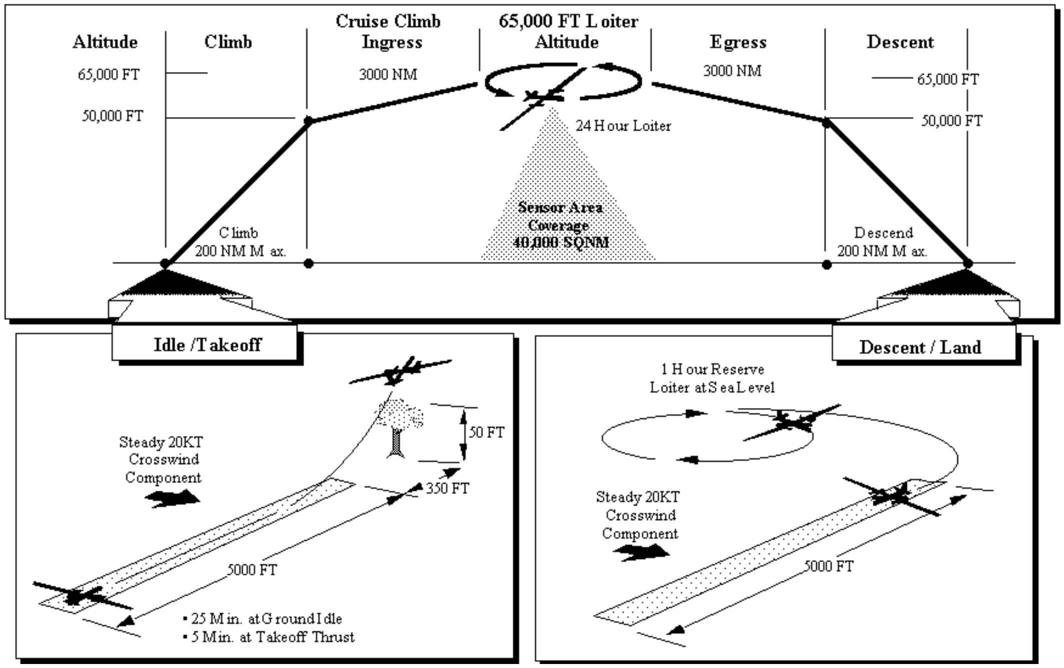
The *Global Hawk* has impressive characteristics and capabilities. The AV will operate at ranges up to 3,000 NM from its launch station and loiter on-station for approximately 24 hours (at that range) at altitudes greater than 60,000 feet (see Table 3 for system characteristics). *Global Hawk* will employ both EO/IR and SAR sensors generating both wide-area and spot imagery while standing off from high-threat

environments. Additionally, the AV will have both LOS and satellite data link communications capability. The high operating altitudes and self-defense measures (discussed later in Chapter 4) ensure a high degree of survivability for this unmanned platform.

Table 3: *Global Hawk* UAV System Characteristics

Cost	$10M per vehicle (with EO/IR/SAR), $20M Ground Control Segment
Dimensions	Wingspan – 116.2 ft.; Length – 44.4 ft.; Height – 15.2 ft.
Weight	Max. Takeoff Gross Weight – 25,600 lbs. (includes 14,700 lbs. of fuel)
Runway Requirements	>5,000 ft., automatic takeoff and (with differential GPS) landing
Payload	2,000 lbs. (4,000 lbs. total using wing hardpoints)
Operating Radius	3,000 NM
Duration	24 hours on station, total mission duration approximately 40 hours
Airspeed	350 knots TAS
Altitude	>50,000 ft. (max. ceiling approximately 65,000)
Flight Control	Self-deployable from CONUS to overseas location and land, fully autonomous, DGPS for takeoff/landing, re-taskable in flight
Survivability	Very high altitude, Threat Warning Receiver (TWR), Threat Deception System (TDS), and Towed Decoy System
Deployment	1 C-141/C-5/C-17 for equipment and personnel
C2 Link	Wide band COMSAT (20-50 Mbps), Ku-band commercial (1.5 Mbps), LOS: X-Band Wide band (CDL) (137-275 Mbps)
Sensors	Simultaneous EO/IR (1.0 ft. search, 0.5 ft. spot, EO: NIIRS 6, IR: NIIRS 5), SAR (1 m search, 0.3 m spot) capable; SAR only via Ku-band or LOS; capable of 40,000 sq. NM search imagery, or 1,900 spot image frames per 24 hr. mission with 20 m CEP accuracy

Global Hawk will deploy from well outside the theater of operations, followed by an extended on-station time in low- to moderate-threat environments (see Figure 9 for *Global Hawk* Mission Profile).

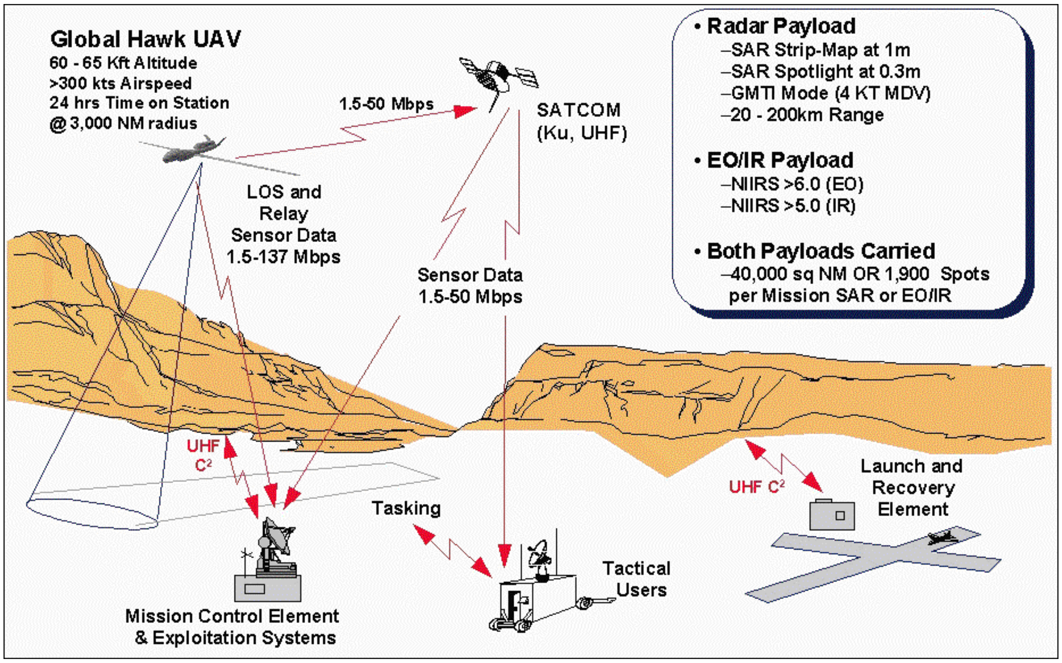


Source: Extracted from the ACC Endurance UAV CONOPS, 3 December 1996—Version 2

Figure 9: Notional *Global Hawk* (Tier II+) Mission Profile

Global Hawk can use either Ku-band commercial satellite data link or the LOS CDL to transmit data back to the MCE. The AV will transmit sensor data at rates up to 137 Mbps over the CDL and will transmit at rates between 1.5 Mbps utilizing the Ku-band. The imagery will then be disseminated from the MCE directly to appropriately equipped exploitation systems and tactical users in the field at a rate of 1.5 Mbps to 137 Mbps depending upon the capacity of the available link and capability of the ground receive terminal (see Figure 10 for *Global Hawk* Employment Concept).

Global Hawk will possess an on-board recorder capable of capturing up to 2 hours (at 50 Mbps rate) of wide area search imagery, with the capability to downlink from the recorder upon command. SAR imagery will be transmitted as formed images from the MCE; EO/IR imagery data will be transmitted as 1k x 1k frames and mosaiced (assembled into a composite picture) in the MCE.



Source: Extracted from the ACC Endurance UAV CONOPS, 3 December 1996—Version 2

Figure 10: *Global Hawk* Employment Concept

Chapter 3

The Air Refueling Rendezvous and Controlling the UAVs During the Air Refueling

I will give up a tank battalion for a UAV company.
--*Maj General Kern, 4th Infantry Division, Commander*

The growing importance of UAVs is clearly captured by the above statement of Major General Kern. Imagine, however, if the UAV's capabilities were further enhanced by an increased on-board equipment capacity and on-station loiter time. This capability is possible with existing technology without building extremely large UAVs with an increased fuel capacity. The solution is to retrofit and design UAVs with an air refueling system. Aerial refueling has become commonplace and the incorporation of an air refueling system into the UAV is just a technical engineering problem. The much larger questions are: how will the UAV rendezvous with the tanker and who will control the UAV during the air refueling.

The chapter begins with some brief definitions of air refueling terms to help the reader understand air refueling terminology. Next, to help answer the question of how the receiver (the UAV in our case) and tanker will the get together, the rendezvous altitude block is explained in detail followed by a thorough elaboration on the point

parallel and enroute rendezvous'.[13] The last portion of the chapter is dedicated to the question of how to control the UAV during the aerial refueling.

Air Refueling Terms

There are several important air refueling terms that one must understand before undertaking a thorough discussion of air refueling. The ***air refueling initial point*** (ARIP), is a point located ahead of or upstream from the ***air refueling control point*** (ARCP), where the receiver(s) (e.g., the aircraft to be refueled) can get a verification of his position, both geographically and in relation to the tanker, using available navigational aids. The ***rendezvous control time*** (RZCT) is a general term used to apply to any control time (e.g., the time the tanker and receiver aircraft will joinup) utilized for accomplishing a rendezvous between tanker and receiver at a specific point (i.e., the ARCP, ARIP/RZIP, etc.). The ***air refueling control time*** (ARCT) is the RZCT utilized during a point parallel rendezvous and is the planned time that the receiver and tanker will arrive over the air refueling control point (ARCP). The time over the ARIP is used to confirm or correct the estimated time of arrival (ETA) to the ARCP. The ARCP is the planned geographic point over which the receiver(s) arrive in the ***observation/precontact position*** with respect to the assigned tanker. The observation or precontact position is the position approximately 50 feet behind and slightly below the tanker boom nozzle where the receiver stabilizes before being approved to proceed or "cleared" to the contact position. The ***contact position*** is the position when the boom operator is able to insert the boom into the receiver's air refueling receptacle and a pumping condition is established

[13] The two most commonly used air refueling rendezvous' are the point parallel and the enroute.

(e.g., a confirmed contact in both the tanker and receiver aircraft); or simply stated the position when the tanker and receiver aircraft are linked together. The contact position is generally defined in terms of the boom position and is normally 12 feet of boom extension, 30 degrees of boom elevation, and zero degrees of boom azimuth. The ***air refueling exit point*** (AREX) is a designated geographic point at which the refueling pattern or "track" terminates. The ***end air refueling point*** (EAR) is a planned point or actual position within the confines of the air refueling track where all refueling operations/requirements are complete. The ***air refueling time*** is the planned elapsed time from the ARCP to completion point. The ***air refueling block*** is the altitudes reserved for the tanker and receiver aircraft to conduct air refueling operations.

The Rendezvous

The Air Force's Basic Flight Crew Air Refueling Manual (T.O. 1-1C-1-3) defines the air refueling rendezvous as: "the procedures employed to enable the receiver(s) to reach the precontact positions behind the assigned tanker(s) by electronic, radio, and/or visual means."[14] Simply stated, the basic rendezvous is nothing more that a set of procedures and actions used to bring two aircraft into close proximity in order to expedite the closure, contact, off-load fuel, and disconnect so the receiver may proceed on with its tasked mission in the most expeditious manner without having to land and refuel.

The basic types of rendezvous procedures are: the point parallel, the on-course, and the enroute. The only difference between the on-course and the enroute rendezvous' is the on-course is designed for the purpose of joining-up the receiver and tanker shortly

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[14] Technical Order (T.O.) 1-1C-1, *Basic Flight Crew Air Refueling Manual*, 15 April 1994, 1.

after takeoff. After join-up, the tanker and receiver aircraft proceed to the air refueling track as a cell formation (cell formation is normally defined as all aircraft established within the specified/assigned altitude block and within three nautical miles of the tanker aircraft). Conversely, the enroute rendezvous is designed to bring the tanker and receiver aircraft together at a specified geographic point after the tanker and receiver are leveled-off at their respective cruise altitudes and away from their departure bases. Since the intent of this study is to focus on the air refueling of UAVs once underway to their assigned missions and not immediately after takeoff, the discussion will be limited to the Point Parallel and the Enroute rendezvous'.

Rendezvous Altitude Block

Generally, three consecutive altitudes will be requested for the rendezvous and air refueling (for example Flight Level (FL) 270 or 27,000 feet MSL through FL 290 or 29,000 feet MSL). Normally the tanker will be at the middle altitude and the receiver at the bottom altitude (FL 280 and FL 270 respectively in this example). This provides a minimum of 1,000 feet between the tanker aircraft and the receiver aircraft during the rendezvous and 1,000 feet above and below the refueling formation once the rendezvous is complete.[15] If the tanker is refueling multiple receiver aircraft, additional altitudes should be requested to provide a minimum of 1,000 feet between the highest receiver aircraft and the lowest tanker. The requested altitude block should provide 1,000 feet above and below the refueling formation once the rendezvous is complete. The 1,000 foot block of airspace above the highest tanker is not mandatory if airspace constraints do

[15] The rendezvous is considered complete when the receiver has closed to the precontact or ready position (defined as approximately 50 feet behind the boom nozzle).

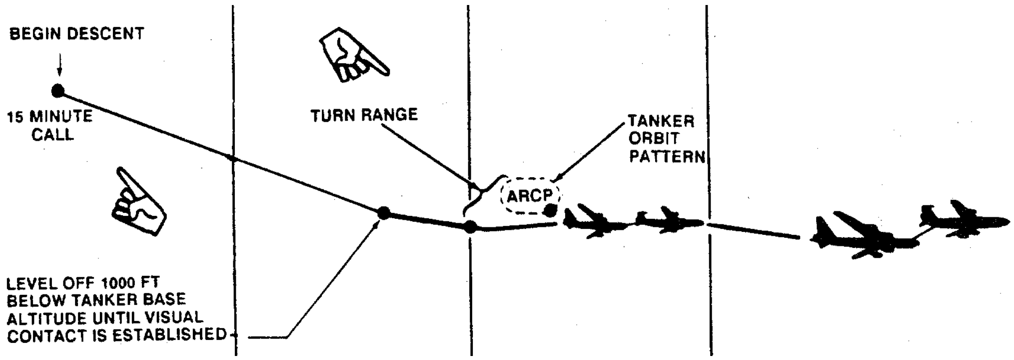
not allow for this airspace cushion, however, the altitude block requested must always provide a 1,000 foot barrier between the lowest tanker aircraft and the highest receiver aircraft.

Point Parallel Rendezvous

The point parallel is an air refueling rendezvous where the tanker aircraft delays in a left-hand racetrack orbit pattern at the ARCP while the receiver aircraft flies from the ARIP downtrack towards the ARCP. When utilizing point parallel rendezvous procedures, the tanker aircraft should arrive at the ARCP 15 minutes prior to the ARCT.[16] The tanker aircraft enters an orbit pattern (see Figure 11), described as a racetrack pattern to the left using 2 minute legs (approximately 14 nm in length) and 30 degree bank turns with the ARCP at the downstream leg that coincides with the receiver's inbound track from the ARIP.[17] If contact with the receiver has not been established prior to the ARCT, the tanker will plan to cross over the ARCP at the ARCT and will delay a minimum of 10 minutes, or as specified by directives. For timing purposes, the tanker may intercept the backside of the orbit and head outbound toward the receiver without first overflying the ARCP.

[16] This time may be reduced to 10 minutes if the distance from the ARIP to ARCP is approximately 70 nm; normal distance between the ARIP and the ARCP is 100 nm.

[17] The normal direction of flight for an air refueling track is from the ARIP over the ARCP to the AREX and is termed flying downtrack/downstream. The terms uptrack/upstream are used when the tanker and/or receiver's direction of flight go against the normal direction of flight on the air refueling track.



Source: Extracted from T.O. 1-1C-1-3.

Figure 11: Point Parallel Rendezvous Profile

For point parallel rendezvous', three critical parameters must be calculated by the tanker aircrew to ensure a successful rendezvous and air refueling: turn range (TR)[18], offset[19], and turn back timing. These computations must be done correctly to ensure the tanker rolls out on course and in front of the receiver inbound to the ARCP. The TR is computed by adding the tanker's true airspeed (TAS) to the receiver's true airspeed and applying the drift correction obtained from the inbound leg between the ARIP and the ARCP.

[18] The TR is the computed nose-to-nose distance between the tanker and receiver at which the tanker aircraft initiates his final turn to the air refueling track to roll out in front of the receiver aircraft.

[19] The distance the tanker aircraft must be displaced from the air refueling track to compensate for the tanker turn radius so his final turn will roll the tanker aircraft out on course.

TURN RANGE

		DRIFT CORRECTION HEADING INTO ARCP							NOTES
		+15	+10	+5	0	-5	-10	-15	
	1000	22	23	25	26	28	30	32	3 NM ROLLOUT RANGE
	975	21	22	24	25	27	28	30	
C	950	20	22	23	24	25	27	29	
	925	19	21	22	23	24	26	28	
L	900	19	20	21	22	24	25	27	
	875	18	19	20	21	23	24	26	
O	850	17	18	19	20	22	23	24	
	825	16	17	18	19	20	21	23	
S	800	15	16	17	18	19	21	22	
	775	15	16	16	17	18	20	21	
U	750	14	15	16	17	18	19	20	
	725	13	14	15	16	16	17	18	
R	700	12	13	14	15	16	16	17	
	675	10	10	11	12	12	13	14	½ NM ROLLOUT RANGE (A-10, A-37)
E	650	9	10	11	11	12	13	14	
	625	9	9	10	10	11	12	13	
	600	8	9	9	10	11	12	12	
	575	7	8	8	9	10	11	11	
R	550	7	7	8	8	9	10	10	
	525	6	7	7	8	8	9	9	
A	500	6	6	7	7	8	8	9	
	475	5	6	6	7	7	8	8	
T	575	6	7	8	6	9	10	11	1 NM ROLLOUT BEHIND C-130
	550	6	6	7	8	9	10	11	
E	525	5	6	6	7	8	9	10	
	500	5	5	6	6	7	8	9	
	475	4	4	5	5	6	7	8	

OFFSET

		DRIFT CORRECTION HEADING INTO ARCP							NOTES
		+15	+10	+5	0	-5	-10	-15	
	460	7	8	9	11	12	14	16	30° BANK
T	440	6	7	8	10	11	13	15	
A	420	6	7	8	9	10	12	14	
N	400	5	6	7	8	9	11	12	
K	380	5	6	6	7	9	10	11	
E	360	4	5	6	7	8	9	10	
R	340	4	4	5	6	7	8	9	
	320	3	4	4	5	6	7	8	
T	300	3	4	4	5	5	6	7	
A	280	3	3	4	4	5	6	6	
S	260	2	3	3	4	4	5	5	
	240	2	2	3	3	3	4	4	

Source: Extracted from T.O. 1-1C-1-3.

Figure 12: Turn Range/Offset Chart

For example, if the tankers TAS is 425 knots true air speed (KTAS) and the receiver's TAS is 450 KTAS then the combined TAS is 875 KTAS. If the drift inbound from the ARIP to the ARCP is 5 degree left (+5), then the computed turn range is 20 nm (see Figure 12 above). The proper offset is computed using the tanker TAS and the drift on the inbound leg of the air refueling track from the ARIP to the ARCP. In this example, the computed offset would be 8 nm. The final turn in front of the receiver occurs after the tanker orbit delay and puts the tanker and receiver on course and on speed to ensure they meet at the ARCP.

If definite range information between the tanker and receiver is not available, timing can be used to approximate a 21 nm turn range. To use turn back timing, a timer

is started when the range between the tanker and receiver aircraft is known (i.e., receiver aircraft departing the ARIP or the distance indicated on the air-to-air tacan). To calculate the time required before initiating the final turn to the rendezvous/rollout heading, enter the turn range timing chart (Figure 13) with the known nose-to-nose distance (obtained from the air-to-air tacan) and closure rate (the sum of tanker and receiver true airspeeds as outlined above).[20]

CLOSURE RATE \ DISTANCE	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
740	:44	1:08	1:32	1:56	2:21	2:45	3:09	3:34	3:58	4:22	4:46	5:11	5:35	6:00	6:24
760	:43	1:07	1:30	1:54	2:17	2:41	3:05	3:28	3:52	4:16	4:39	5:03	5:27	5:51	6:14
780	:42	1:05	1:28	1:51	2:14	2:37	3:00	3:23	3:46	4:10	4:32	4:55	5:19	5:42	6:05
800	:41	1:03	1:26	1:48	2:11	2:33	2:56	3:18	3:41	4:04	4:26	4:48	5:11	5:33	5:56
820	:40	1:01	1:23	1:45	2:07	2:29	2:51	3:13	3:35	3:58	4:19	4:41	5:03	5:25	5:47
840	:39	1:00	1:21	1:43	2:04	2:26	2:47	3:09	3:30	3:52	4:13	4:34	4:56	5:17	5:39
860	:38	:58	1:19	1:40	2:01	2:22	2:43	3:04	3:25	3:46	4:07	4:28	4:49	5:10	5:31
880	:37	:57	1:17	1:38	1:58	2:18	2:39	2:59	3:20	3:40	4:01	4:22	4:42	5:02	5:23
900	:35	:55	1:15	1:35	1:55	2:15	2:35	2:55	3:15	3:35	3:55	4:15	4:35	4:55	5:15

Source: Extracted from T.O. 1-1C-1-3.

Figure 13: Turn Range Timing Chart

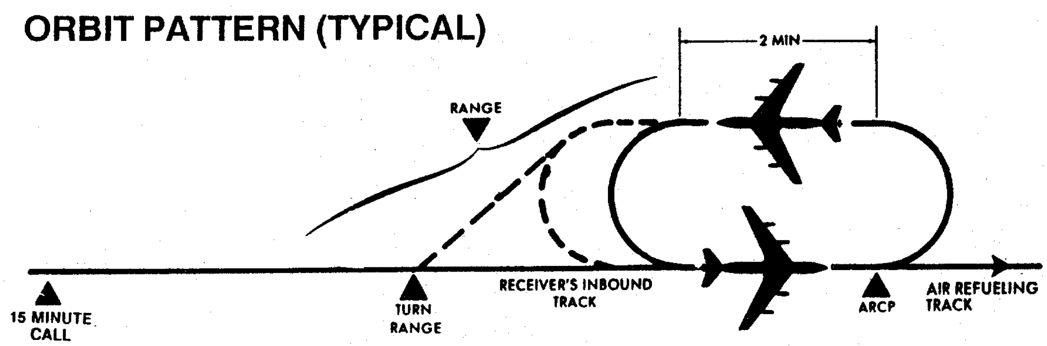
Timing is an effective means to backup the primary rendezvous equipment (the inertial navigation system (INS)/doppler navigation system (DNS) and air-to-air tacan). This calculation is critical to the point parallel rendezvous should the air-to-air tacan break lock (e.g., lose its radio signal and thus its distance readout).

Generally the receiver aircraft arrives at the air refueling initial point (ARIP) approximately 15 minutes prior to the ARCT. The receiver departs the ARIP and proceeds downtrack towards the tanker aircraft. Timing is critical and the receiver aircraft must adjust his airspeed and timing in order to depart the ARIP at the precise time

[20] A good rule of thumb is to subtract 4 seconds for each nm over 21 nm and add 4 seconds for each nm under 21 nm.

to ensure his arrival at the ARCP at the pre-determined time designated the air refueling control time (ARCT).

As the receiver aircraft crosses the ARIP, the tanker aircraft has made a 180 degree turn and is now heading uptrack towards the receiver. The tanker will use the inertial navigation system and doppler navigation system (INS/DNS) to maintain the proper offset from the inbound track (see Figure 14). The tanker proceeds uptrack towards the receiver and at the proper moment makes a left hand turn to rollout approximately one mile in front of the receiver aircraft.[21] Once the tanker is positioned in front of the receiver, the receiver begins a gentle closure to the pre-contact position.



Source: Extracted from T.O. 1-1C-1-3.

Figure 14: Orbit Pattern (Typical)

After the receiver stabilizes in the precontact position, the boom operator clears the receiver to the contact position. The receiver aircraft begins a controlled closure (approximately 1 foot/second) and the boom operator effects a contact at approximately 12 feet of boom extension. When the tanker and receiver air refueling systems give

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[21] The proper moment is when the desired turn range is reached (this turn range is backed up by turn back timing). If it is a perfect rendezvous, the tanker will turn at the precise moment when his backup timing expires and he reaches the calculated turn range. The turn range is determined by using air-to-air tacan. These tacan frequencies are located in the communication and rendezvous (C/R) plan in AP/1B, a publication distributed by the US military containing all the published air refueling tracks in the CONUS, and allow the

positive verification of a contact, the tanker pilot energizes the air refueling pumps and begins the fuel offload. Once the offload is complete, the pilot terminates fuel pumping and the boom operator triggers (initiates) a disconnect. The receiver aircraft slowly backs away from the tanker and begins a controlled descent to the bottom of the air refueling block (normally 1,000 below the tanker aircraft).

After completion of air refueling, the tanker pilot requests the desired routing for both the tanker and receiver aircraft. Once the Air Traffic Controller (ARTCC) has positive identification of the receiver aircraft and confirms proper separation between the two aircraft (both vertically and horizontally), the tanker is released from responsibility of maintaining separation between the two aircraft and each aircraft proceeds on its individual flight plan.

Enroute Rendezvous

The enroute rendezvous differs from the point parallel in that the tanker and receiver aircraft joinup at the ARIP versus the ARCP. "An enroute rendezvous may be used when the tanker(s) and receiver(s) fly individual flight plans to a common rendezvous point (RZ) where joinup is accomplished and continue enroute cell formation to the ARCP" (see Figure 15).[22] If a picture perfect enroute rendezvous were accomplished, the tanker and receiver (in this case a UAV) would arrive at the rendezvous point (RZIP/ARIP) at the same time. However, the tanker crew, as a

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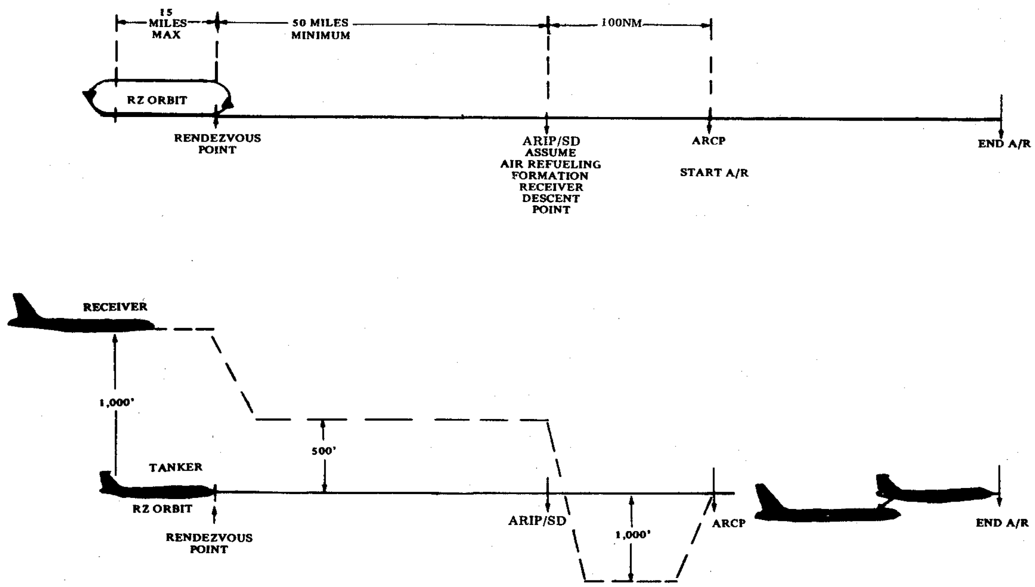
tanker and receiver aircraft to determine the nose-to-nose distance between the two aircraft.

[22] Technical Order (T.O.) 1-1C-1-3, *KC-135 (Tanker) Flight Crew Air Refueling Procedures*, 1 January 1987, Change 5, 1 May 1994, 3-9.

technique, will generally plan to arrive approximately 20 seconds ahead of the receiver at the RZIP/ARIP.[23]

Once the receiver aircraft is in trail of the tanker, the receiver begins a controlled closure to the precontact position. After the receiver stabilizes in the precontact position, the boom operator clears the receiver to the contact position. The receiver aircraft begins a controlled closure (approximately 1 foot/second) and the boom operator effects a contact at approximately 12 feet of boom extension. When the tanker and receiver air refueling systems give positive verification of a contact, the tanker pilot energizes the air refueling pumps and begins the fuel offload. Once the offload is complete, the pilot terminates fuel pumping and the boom operator triggers (initiates) a disconnect. The receiver aircraft slowly backs away from the tanker and begins a controlled descent to the bottom of the air refueling block (normally 1,000 below the tanker aircraft). After the completion of air refueling, the tanker and receiver procedures are identical to those outlined above in the point parallel rendezvous section.

[23] This ensures the tanker is in front of the receiver and if weather conditions permit, can visually acquire the receiver.



Source: Extracted from T.O. 1-1C-1-3.

Figure 15: Example of an Enroute Rendezvous

Controlling the UAV during Air Refueling

Control of the UAV during air refueling is of the utmost importance. In order to ensure positive control of the AV at all times during the rendezvous and air refueling, three possible methods of control seem logical: a pilot and payload operator (PPO) workstation (similar to the one used to control the *Predator* UAV), an airborne platform such as an AWACS with an aerial vehicle operator (AVO), or a second boom operator in the aft portion of the tanker with a set of controls to fly the UAV during the refueling.

The *Predator* GCS is a 30x8x8 triple axle trailer and contains the pilot and payload operator (PPO) workstations which control the UAV. The AVO portion of the PPO consists of two 17-inch monitors which display the primary AV status and performance data; desktop controls for throttle, flap, landing gear, keyboard with trackball and joystick controls; and floor-mounted AV brake/rudder control pedals. The display of information can be modified to optimize the screen for each operator. A nose-

mounted video camera provides primary visual information for manual vehicle operation. This visual information is used for takeoffs and landings and is displayed on one of the primary 17-inch monitors.

The Payload Operator portion of the PPO consists of two 17-inch primary video display monitors; two 9-inch secondary display monitors; and the same desktop and floor mounted controls as the air vehicle operator station. It is important to note that the PPO functions can also be performed at the AVO workstation, however the converse is not true, all of the AVO functions cannot be performed at the PPO workstation.

The second option, an airborne AVO (located in the rear of an aircraft such as an AWACS), would have the same controls as the *Predator* PPO workstation and perform the same functions. The only difference is the AVO would be airborne versus the land-based PPO (which most UAV systems currently employ).

The last option is a second boom operator positioned adjacent to the primary boom operator in the aft portion of the tanker aircraft (commonly referred to as the boom pod). The secondary boom operator would have a workstation consisting of a primary and secondary video display, a set of flight controls, a throttle control system, and an indication system (control panel) to confirm when the secondary boom operator has positive control of the AV and display the altitude, airspeed, distance measuring equipment (DME), and heading information of the UAV.

The third option, the secondary boom operator position, has several advantages over the other two options. First of all, not only would the boom operator have the video display from the UAV perspective but would also have the secondary boom's visual perspective and confirmation as well. Second, due to the close proximity of the UAV to

the secondary boom operator, there would be no significant time delay in the inputs to the engine and flight controls.[24] A third advantage is the secondary boom operator would be able to talk directly to the primary boom operator without relying on satellite or radio relays for communications. The last advantage is the ability of the secondary boom operator to feel the air turbulence and visually see the effects on the UAV during the air refueling. This allows the secondary boom operator to make immediate inputs to the UAV based upon the movement of the tanker aircraft, his visual cues, and the physical reactions of the UAV to the air turbulence/adverse weather effects.

A proposed method for the sequence of events for the rendezvous and air refueling would occur in the following manner.[25] A ground- or air-based AVO would control the UAV through completion of the rendezvous with the tanker aircraft. Then, the ground- or air-based AVO would give positive control of the UAV to the secondary boom operator (once the UAV is within one nm of the tanker aircraft and leveled off at an altitude 1,000 feet below the tanker); positive handoff would be confirmed visually (by some sort of indication such as the illumination of a light on the UAV control panel) and/or by radio communication. Once the secondary boom operator confirms control of the UAV, he performs a controllability check of all flight and engine controls. After the controllability check is complete, the secondary boom operator flies the UAV to the precontact position.

[24] As per an interview with Norman S. Sakamoto, Vice President Engineering Special Programs/Advanced Development, Teledyne Ryan Aeronautical in San Diego, Ca., the time delay experienced in flight control and engine inputs by a ground- or air-based controller located out of the refueling area could be as long as 3.5 seconds.

[25] Keep in mind the air- or land-based AVO can perform the same functions as the secondary boom operator. This section was written from the secondary boom operator’s perspective to avoid repetition of the same sequence of events.

The primary boom operator clears the UAV to the contact position and the secondary boom operator flies the UAV to the contact position and the primary boom operator initiates the contact. The tanker aircraft offloads the required amount of fuel to the UAV and the primary boom operator initiates a disconnect when the offload is complete. The secondary boom operator backs the UAV away from the tanker aircraft and once the UAV is well clear (aft of the precontact position) the secondary boom operator begins a slow descent with the UAV. Once the UAV is established in a position 1,000 ft. below the tanker and at least one nm in trail, positive control of the AV is given back to the air- or land-based AVO. The AVO assumes responsibility for clearances and control of the AV, and the AV departs the refueling track for its assigned mission. The air refueling portion of the mission is now terminated.

Chapter 4

Comparison and Analysis of Current AF UAV Systems, Rendezvous', and Methods of Control of the UAV During Aerial Refueling

> *UAVs are slowly but surely becoming a large part of the entire spectrum of air assets. There are missions out there for which there is no reason to put a person in harm's way. Plus an unmanned vehicle can do things that a manned-aircraft can't because of the limitations of the human body.*
>
> *--Eric Knutson, UAV Program Manager, Skunk Works*

This chapter begins with a discussion of the four key issues influencing the air refueling of UAVs: survivability, operating radius and mission duration, range versus payload tradeoff, and adverse weather. Each of these key issues will be compared for each of the three current AF UAV systems: *Predator*, *DarkStar*, and *Global Hawk*. The discussion will then turn to a comparison of the point parallel and enroute rendezvous' to determine the type of rendezvous best suited for the UAV, both now and in the future. The chapter closes out with an analysis of the methods for controlling the UAVs during the air refueling portion of its mission.

Survivability

Unless the UAV can survive its tasked mission, there is no need for the platform to be air refuelable. Each of the three UAVs *Predator*, *DarkStar*, and *Global Hawk* have unique characteristics which make them survivable in their operating environments.

The ***Predator***[26] is the most vulnerable of the three platforms to hostile threats. The major reason for this is the *Predator*'s operating environment. The AV is designed to operate at altitudes no greater than 25,000 ft MSL at airspeeds between 60-110 knots TAS; 15,000 ft MSL and 85 knots TAS are the nominal altitude and airspeed.[27] Additionally the sensor payloads only provide enhanced resolution at lower altitudes (approximately 5,000 ft MSL). The threats in this operating regime are numerous including: radio frequency and infrared (IR) guided surface-to-surface missiles; anti-aircraft artillery (AAA); and second, third, and fourth generation combat aircraft equipped with the latest guns, rockets, and air-to-air missiles (AAM). Additionally, while operating at the lower altitudes, *Predator* may find itself vulnerable to more unsophisticated, visually acquired AAA and man-portable surface-to-air missile (SAM) systems.

The *Predator* UAV does have some inherent protection. Although the *Predator* UAV was not designed to meet low signature requirements, its small size, composite material construction, and shape enhance its low signature. However, the AV does not contain an onboard electronic attack (EA) system, therefore the operator receives no warning of an attack against the UAV. Therefore, the *Predator* UAV is best utilized

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[26] The bold italics font was added for differentiation of UAV systems and emphasis.

[27] Air Combat Command (ACC), *Concept of Operations (CONOPS) for Endurance Unmanned Aerial Vehicles (UAV)*, 3 Dec 1996-Version 2, Section 1, 3.

either in a standoff role or by overflying targets outside known adversary engagement envelopes in order to defeat hostile SAM and aircraft systems.

In contrast with the *Predator* UAV, ***DarkStar*** is designed using low observable (stealth) technology characteristics. By combining stealth with its high-altitude employment profile, *DarkStar* becomes capable of penetration surveillance and reconnaissance missions in an integrated air defense system (IADS) environment. While operating in these high-threat areas, *DarkStar*'s low observable characteristics will limit or nullify the most advanced hostile aircraft and SAM system's ability to successfully engage it. Furthermore, "both classes of the high altitude UAVs will be capable of encryption, while the *Predator* UAV is designed to operate with unencrypted data links."[28] Unfortunately for this discussion, the AV signature information for the *DarkStar* UAV is currently classified and not releasable at this time.

Unlike the *Predator* UAV, the unique operating profiles of the ***Global Hawk*** UAV enable it to operate worldwide with only small numbers of enemy weapon systems able to threaten its mission. This is due mostly to the air vehicle's high operating altitudes (50,000 – 65,000 ft MSL). However, some threats to the *Global Hawk* UAV include high altitude SAM systems and high altitude interceptor aircraft. Because of its lack of low observable characteristics, *Global Hawk* will employ standoff tactics whenever possible to avoid known threats.

Additionally, *Global Hawk* uses early threat detection and warning capabilities (both onboard and offboard) to assist with dynamic threat avoidance. *Global Hawk*'s survivability is increased by the "AN/ALR-89(V) Threat Warning Receiver (TWR), a

[28] Ibid., 4.

Threat Deception System (TDS) including onboard jammers, appliques, and expandable decoys, and the ALE-50 Towed Decoy System."[29] These systems can operate fully automated or manually, either as independent systems or as a single integrated survivability suite. "The TWR is fully integrated into the flight computer to provide automatic maneuvering of the air vehicle to minimize detected threats."[30] These capabilities along with the onboard electronic counter-measures and integrated composite force planning make the *Global Hawk* highly survivable in the light to moderate threat environments.

Operating Radius and Mission Duration

The operating radius and mission duration are two key UAV characteristics that must be considered in the UAV air refueling equation. After performing its tasked mission, the UAV must be able to exit the area of operations, cruise to the air refueling track to meet the tanker aircraft, and then return after air refueling for its subsequent mission. If the AV does not have the operating radius to keep the tanker aircraft out of harms way, then aerial refueling is not an option. To lose a tanker aircrew and aircraft because they were moved to close to the threat area defeats the whole rationale for using UAVs—to prevent loss of life.

The operating radii and mission duration figures for all three current AF UAV systems are located in Table 4. The *Predator* and *DarkStar* UAVs both have a 500 nm operating radius from their departure base. However, the loiter capability available for each AV while operating at these radii differ significantly. The *Predator* UAV offers

[29] Ibid., Section 2, 11.
[30] Ibid.

approximately 24 hours on-station loiter time while the *DarkStar* UAV offers only a mere 8 hours of loiter time.[31] However, the differential in loiter capability between the *Predator* and *DarkStar* UAVs is quite deceiving. This fact will be brought to light in the following paragraphs.

Air refueling tracks are normally located several hundred miles away from the threat environment. This is done to protect the tanker aircraft by providing a buffer zone between the tanker aircraft and the enemy threat. Therefore, the receivers are required to exit the unfriendly territory, cruise to the air refueling track, refuel, and the return to the fight. For the *Predator* and *DarkStar* UAVs, the requirement to cruise to the tanker air refueling track would cancel a sizeable portion of their loiter time—thereby significantly decreasing their effectiveness in the area of operations. Consider for a moment the following scenario.[32]

[31] The low observable requirements drove the size and shape of the *DarkStar* UAV. The strange shape of the *DarkStar* UAV significantly limits the internal fuel capacity.

[32] In order to simplify the scenario and minimize the discussion on aerodynamics, the assumption will be made that the UAVs are operating in a wind-free environment. This assumption is made because in a no-wind environment true air speed (TAS) equals ground speed (GS); this will simplify the required computations and make the comparisons much easier.

Table 4: Comparison of Endurance UAV Capabilities

Characteristic	Predator	Global Hawk	DarkStar
Gross Take-off Weight	>1873 lbs (EO/IR)	22,914 lbs	8,600 lbs
Wingspan	48.7 feet	116.2 feet	69 feet
Mission Duration **Operating Radius**	24+ hours on station @ 500 NM	24 hours on station @3000 NM	> 8 hours on station @ 500 NM
Maximum Endurance	40+ hours	42+ hours	N/A
Ferry Range	N/A	15,000 NM	N/A
Payload	>450 lbs	2,000 lbs	1,000 lbs
True Air Speed	60-110 knots	350 knots	>250 knots
Loiter altitude	25,000 feet max. 15,000 Feet Nominal	>50,000 feet	>45,000 feet
Survivability Measures	None	Threat warning and ECM	Very low observable
Command and Control	UHF MILSAT/Ku Band SATCOM/C-band LOS	UHF MILSAT/LOS	UHF MILSAT/LOS
Sensors	SAR: 1 ft IPR, Swath Width Approx. 800 m EO: NIIRS 7 IR: NIIRS 5 Simultaneous Dual Carriage	SAR: 1 m search; 0.3 m spot EO: NIIRS 6 IR: NIIRS 5 Simultaneous Dual Carriage	SAR: 1 m search 0.3 m spot EO: NIIRS 6 IR: None Single Carriage
Coverage per mission	13,000 sq NM search imagery	40,000 sq. NM. search imagery, or 1,900 spot image frames	14,000 sq. NM search imagery, or 620 spot image frames
Sensor data transmission	Ku Band: 1.5 Mb/sec UHF SATCOM 16Kb/sec LOS: C-band 4.5Mb/sec	Wide band COMSAT: 20-50 Mbits/sec LOS: X-Band Wide Band (CDL): 137-275 Mbits/sec	Narrow band COMSAT: 1.5 Mbits/sec LOS: X-Band Wide band (CDLS): 137-275 Mbits/sec
Deployment	6 C-141s or 10 C-130s 2/C-5/C-17	Self deployable, SE requires airlift	3 C-141s or Multiple C-130s
Ground Control Station	LOS & OTH	Maximum use of GOTS/COTS (LOS & OTH)	Common with Tier II Plus
Data Exploitation	Existing and Programmed: JSIPS, CARS, MIGS, MIES, JIC, NPIC	Existing and Programmed: JSIPS, CARS, MIGS, MIES, JIC, NPIC	Existing and Programmed: JSIPS, CARS, MIGS, MIES, JIC, NPIC

Source: Extracted from the ACC Endurance UAV CONOPS, 3 December 1996—Version 2

The loiter position of the UAV is located deep in the heart of the fictitious country, Yurmama. From the loiter area, it is approximately 275 nm to the border of this

unfriendly territory. After the UAV has performed its tasked mission, it must cruise from its current loiter position to the air refueling track. The air refueling track is located approximately 225 nm from the border of Yurmama. This means the UAV must cruise some 500 nm before it reaches the tanker aircraft. Based upon the best case scenarios (i.e., best ground speed possible for each UAV), Table 5 depicts the enroute time from the theater of operations to the refueling track. This 500 nm distance places the *Predator* and *DarkStar* UAVs at their maximum operating radius and upon arrival at the air refueling track the *Predator* UAV would only have approximately 1 hour worth of fuel reserve[33]; the *DarkStar* UAV would only have 30 minutes of fuel reserve remaining. This allows very little time for the rendezvous and closure with the tanker aircraft.

Table 5: Comparison of UAV Cruise Times to A/R Track

	Predator	***DarkStar***	***Global Hawk***
Ground Speed	110 Knots	250 Knots	350 Knots
Minutes	272.7 Min	120 Min	85.7 Min
Hours + Minutes	4 Hrs + 32.7 Min	2 Hrs + 00 Min	1 Hr + 25.7 Min
Hrs + Min + Sec	4 Hrs + 32 Min + 42 Sec	2 Hrs + 00 Min + 00 Sec	1 Hr + 25 Min + 42 Sec

In contrast to the *Predator* and *DarkStar* UAVs, *Global Hawk* could perform its normal mission loitering in the theater of operations for approximately 24 hours, cruise to the air refueling track, and arrive at the refueling track with approximately 8 hours of fuel reserve. This large fuel reserve provides flexibility for the UAV to circumnavigate adverse weather, mobile enemy air defenses, and provides the capability for the UAV to orbit should the tanker be delayed.

[33] Fuel reserve is the amount of fuel required upon arrival at the destination airfield and accounts for: an approach and missed approach at the destination airfield, followed by an approach and landing at an alternate airfield.

The limited operating radius of the *Predator* and *DarkStar* UAVs place them at a huge disadvantage when compared with the *Global Hawk* UAV. The inability to drive even 500 nm to the refueling track to avoid such things as enemy integrated air defense systems, prohibited airspace, no-fly zones, and unfriendly airspace make *Global Hawk* the platform of choice for air refueling when comparing operational ranges.

However, survivability and operational radius are not the only issues to consider in the air refueling equation, the range versus payload question must be addressed not to mention the effects adverse weather will have on each of the UAV systems.

Range vs. Payload and Adverse Weather

One of the principles of aerodynamics is any time you increase the payload of any aircraft the range is decreased and the UAV is no exception (assuming all other factors remain the same). Air refueling provides an option to beating this principle of aerodynamics, provided the UAV has enough range capability remaining with the increased payload to cruise to the air refueling track.

The *Predator* UAV carries 108 gallons of fuel internally (660 pounds of fuel).[34] Due to the low fuel burn rate of the AV, *Predator* is able to stay airborne for approximately 40 hours with this small amount of fuel. However, the AV does have its limitations. The AV is only capable of carrying 450 lbs. of payload and for every 20 lbs. of payload added above the basic EO/IR configuration, the endurance is reduced by one

[34] Office of the Under Secretary of Defense (Acquisition & Technology) (OUSD(A&T)), *UAV Annual Report FY 1997* (Washington, D.C.: Defense Airborne Reconnaissance Office (DARO), 6 November 1997), 23.

hour.[35] This tradeoff of range/endurance for such a small increase in payload is not worth the significant loss in loiter capability.

Not only is the *Predator* UAV limited by payload, the UAV's ability to operate in adverse weather conditions is extremely limited. The AV is not water-proof and is limited to 14 knots (kts) of crosswind during takeoffs and landings. The AV is operable only in mildly adverse weather, those equivalent to instrument flight by a light civil aircraft.[36] Therefore, the *Predator* UAV is suited for operations only in areas with favorable weather and must avoid areas of icing, heavy precipitation, or high winds.

In comparison, the *DarkStar* UAV carries 416 gallons of fuel internally (3,240 pounds of fuel).[37] Although the *DarkStar* carries much more fuel than the *Predator* UAV, its increased fuel burn rate limits its mission duration to approximately 12 hours.[38] Although the figures for the tradeoff between payload and range are classified, the system is capable of carrying only 1,000 pounds of payload and only a single sensor carriage (either an EO or SAR sensor). "When DARO set the high-stealth requirement for *DarkStar*, it sacrificed range, payload, and sensor flexibility."[39] Furthermore, the design of the fuel system will not accommodate a single point refueling receptacle. Unfortunately, the effects of adverse weather upon the *DarkStar* UAV are yet to be decided upon and are therefore not available at this time.

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[35] ACC CONOPS for Endurance UAVs, Section 2, 4.
[36] Ibid., 5.
[37] UAV Annual Report FY 1997, 23.
[38] Ibid.
[39] "Send In The Drones," *Popular Science*, October, 1995.

The *Global Hawk* UAV carries 2,160 gallons of fuel internally (14,700 pounds of fuel), a significant increase over the *Predator* and *DarkStar* UAVs.[40] Combine this large fuel capacity with its minimal fuel burn rate and the *Global Hawk* UAV is able to stay airborne for approximately 40 hours. Besides being fuel efficient, the AV is capable of carrying 1,960 lbs. of internal payload and has two hardpoints, one on each wing, capable of carrying another 1,000 lbs. each. The total payload capacity (both internal and external) of the *Global Hawk* UAV make it a very versatile system, capable of accommodating a vast array of sensors, systems, and equipment.

Not only is the *Global Hawk* UAV able to carry a large payload, the UAV's ability to operate in adverse weather conditions is much better than that of the *Predator* UAV. The *Global Hawk* UAV is water-proof and is able to sustain 20 kts of crosswind during takeoffs and landings.[41] The AV's rapid climb rate allow it to climb rapidly through icing conditions to an altitude where the ice will sublimate.[42] Furthermore, the vehicle's airspeed during cruise is sufficient to cope with the jet stream winds and its large control surfaces and fly by wire reaction enable the autopilot to attenuate the effects of high altitude clear air turbulence. Clearly, the *Global Hawk* UAV is a more capable system than the *Predator* and *DarkStar* UAVs for payload carrying capacity and adverse weather operations.

The focus thus far in this chapter has been to compare and contrast the capabilities and limitations of the *Predator*, *DarkStar*, and *Global Hawk* UAVs. The focus now

[40] UAV Annual Report FY 1997, 23.
[41] ACC CONOPS for Endurance UAVs, Section 2, 11.
[42] The *Global Hawk* UAV does have equipment onboard to indicate when operating in icing conditions.

shifts to the comparison and analysis of the point parallel and enroute rendezvous' and the methods for controlling the UAVs during the aerial refueling.

Comparison of Air Refueling Rendezvous'

Either of the two primary air refueling rendezvous', the point parallel or the enroute, are compatible with the current AF UAV systems. However, the enroute rendezvous offers several advantages over the point parallel. First of all, the enroute rendezvous would allows the tanker to meet the receiver much closer to the UAV's theater of operations. This is due simply to the physical layout and design of the air refueling track. During a point parallel rendezvous the tanker joins up with the receiver at the ARCP, whereas with an enroute rendezvous the tanker joins up with the receiver at the ARIP. This is an enormous advantage in that the ARIP is normally positioned approximately 100 nm uptrack from the ARCP, thus placing the position for the joinup 100 nm closer to the UAV's area of operation.

Second, by joining up with the tanker earlier on the air refueling track, the UAV is able to receive its fuel offload much sooner. This is because the UAV will not have to drive an additional 100 nm from the ARIP to the ARCP before joining the tanker. This minimizes the amount of time the UAV will have to spend on the air refueling track and allows the UAV to depart the air refueling track much sooner to accomplish its follow-on mission.

The last advantage of the enroute rendezvous is the maneuvering of the UAV and tanker will be minimized. The enroute rendezvous allows both the UAV and tanker to enter the air refueling track on a straight-line course. The tanker will not have to orbit and waste valuable time waiting to hookup with the UAV. The fact of the matter is the

less maneuvering required the easier the job of the AVO and the tanker aircrew. This would be a tremendous advantage especially when operating in adverse weather conditions with reduced visibility.

It should be obvious that the enroute rendezvous offers several advantages over the point parallel rendezvous. But getting the tanker and UAV together is just part of the air refueling problem, now consideration must be given as to what is the best method for controlling the UAV during the air refueling?

Methods of Controlling the UAV During Air Refueling

The three methods proposed for controlling the UAV during the air refueling are: a pilot and payload operator (PPO) workstation (similar to the one used to control the *Predator* UAV), an airborne platform such as an AWACS with an aerial vehicle operator (AVO), or a second boom operator in the aft portion of the tanker with a set of controls to fly the UAV during the refueling.

Of the three proposed methods of control, the second boom operator option has many advantages over the other two methods. First, the secondary boom operator would not experience a time lag between the time he makes his control inputs and the time the UAV reacts to them. This time lag is inherent in the other two AVO systems because of the requirement to relay the inputs via radio waves when operating beyond line-of-sight (LOS).[43]

Another advantage is the secondary boom operator has his own visual perspective to confirm the video data from the UAV. This would give the secondary boom two

[43] According to Norm Sakamoto, this delay could be as long as 3.5 seconds. Norman S. Sakamoto, Teledyne Ryan Aeronautical, interviewed by author, 13 January 1998.

references to maintain the position of the UAV in relation to the tanker aircraft. Additionally, should the video datalink fail, the boom operator would be able to complete the air refueling visually (weather permitting of course). This equates to a higher mission effectiveness rate because missions would not have to be cancelled should the AVO lose the video datalink.

The final advantage is the ability of the secondary boom operator to communicate directly with the primary boom operator on the tanker aircraft. The two boom operators would be able to talk across the boom pod without broadcasting over the UHF, VHF, or HF radios. This would prevent the compromise of refueling track information as well as the position of the two aircraft. This advantage alone could pay big dividends when operating near or in a highly politically sensitive area where the operation of the UAVs is permitted but not acknowledged.

The benefits of using the second boom operator option are numerous. The absence of the time lag for control inputs, the visual perspective to confirm and backup the video data, and the ability to communicate directly with the primary boom operator without compromising sensitive information make this option the best method for controlling the UAV during the air refueling.

Chapter 5

Conclusions and Implications

Achieving Information Superiority is key to winning future battles. UAVs are envisioned to be an integral part of the Intelligence, Surveillance, and Reconnaissance system providing critical information to the warfighter. As UAV technologies advance, we will explore the possibility of using unmanned vehicles to support other Air Force core competencies.

--1997 United States Air Force Issues Book

The first part of the chapter begins with the author's selection of: the current AF UAV system best suited for air refueling, the type of rendezvous best utilized by the UAV, and the method of controlling the UAV that is most effective for air refueling operations. In the second part of the chapter, the author, assuming that UAVs will be air refuelable in the future, draws some implications for the United States military.

Conclusions

Based upon the data in the previous chapters, the *Global Hawk* UAV is the current AF UAV system best suited for air refueling. The *Global Hawk* UAV's ability to operate worldwide with only minimal threats to its operation makes it a highly survivable system. Although it lacks the low observable (stealth) technology, its high operating altitude (normally above 50,000 feet MSL), aids in its ability to transit enemy airspace unnoticed. *Global Hawk's* use of offboard early threat detection and warning capabilities aids in dynamic threat avoidance. These capabilities are further enhanced by *Global*

Hawk's onboard defensive systems including: an AN/ALR-89(V) Threat Warning Receiver (TWR), a Threat Deception System (TDS), and the ALE-50 Towed Decoy System. Furthermore, the small radar cross section (RCS), the employment of standoff tactics, and the avoidance of known threat areas will make the *Global Hawk* UAV an effective system against most enemy integrated air defense systems (IADS) and highly survivable in light to moderate threat environments.

Besides survivability, the *Global Hawk* UAV's tremendous operating radius, large fuel reserve capacity, ability to operate in adverse weather, and impressive payload capability far surpass that of both the *Predator* and *DarkStar* UAVs. The *Global Hawk* UAV can self-deploy to the theater of operations in almost any type of weather, loiter for an extended period of time (carrying a vast array of sensors, systems, and equipment), and then exit the threat area to refuel before returning for a follow-on mission.

How will the *Global Hawk* UAV joinup with the tanker and refuel prior to its follow-on mission? The most effective solution is utilizing enroute rendezvous procedures. The enroute rendezvous is the best procedure for the *Global Hawk* UAV for several reasons. First, due to the physical design of the air refueling track, the ARIP is approximately 100 nm closer than the ARCP to the UAV's area of operations. Second, because the ARIP is so much closer, the UAV will be able to joinup with the tanker much quicker and therefore receive its offload sooner. The end result for the *Global Hawk* UAV is less time on the refueling track and more time in the theater of operations. Finally, the enroute rendezvous allows the tanker aircraft and UAV to fly a straight-line flightpath into the air refueling track therefore minimizing the maneuvering required to

align the tanker and UAV for air refueling operations (this is extremely important during austere weather conditions).

For controlling the *Global Hawk* UAV during the air refueling, the second boom operator in the aft portion of the tanker is by far the best option. The estimated 3.5 second delay for control inputs to take effect, from either the airborne or ground based AVO, is not acceptable and could cause grave damage before the UAV reacts to inputs—the time required for the second boom operator's inputs to take effect with the UAV only feet away is negligible. Additionally, there is no better primary or backup than direct line-of-sight for refueling operations. The boom operators air refueling training and experience as well as his finesse and precision with "flying" the boom make him a perfect candidate for training as an AVO specifically for the refueling portion of the UAV's mission. Last of all, the second boom operator has the advantage of close proximity to the primary boom operator. The second boom operator is able to discuss the air refueling directly with the primary boom operator without compromising the mission and/or the positions of the two aircraft by broadcasting over the radios.

Implications

The implications of air refuelable UAVs are many and varied, however, this work does not provide sufficient space to discuss them all so the discussion will try to explore the major issues. First and foremost, the UAV air refueling mission would not affect normal tanker refueling operations. All KC-135s and KC-10s are boom equipped and unless the UAV is fitted with a probe air refueling apparatus, the UAV could be refueled on the same mission utilizing the same tanker as the Air Force's manned platforms—this point is extremely critical with the endless demand for tanker refueling support.

Second, with refuelable UAVs a single UAV could perform the missions of two or three unrefuelable UAVs. This means fewer numbers of UAVs would be required to perform the tasked mission and the airspace would be less congested in the theater of operations. Additionally, the smaller number of UAVs requires less support personnel and equipment to keep them mission ready—thus reducing the "footprint" of American presence. The end result is a significant decrease in production and maintenance costs, safer air operations, decreased political tension because of a smaller American presence, and a large logistics support cost savings.

Third, refuelable UAVs would be able to perform worldwide missions taking off from the CONUS and landing in the CONUS. This reduces the forward basing requirements, eases political tensions in areas where American presence is wanted but not welcomed on the ground, and decreases the number of support personnel for its worldwide operations.

Fourth, the enhanced loiter and payload capabilities afforded by air refueling mean the Air Force no longer has to rely solely on manned platforms to perform its more risky and demanding missions. If a UAV is shot down, the AF just loses an expendable piece of equipment. However, if a manned platform gets shot down, the AF must deal with KIA, MIA, or prisoner of war issues—very stressful for all parties involved. The *Global Hawk* UAV can perform many of the missions currently reserved for manned platforms without putting a pilot and aircrew in harms way. *Global Hawk's* internal payload capacity of 1,960 lbs. and its external payload capacity of 2,000 lbs. make it a very versatile system, capable of accommodating a vast array of sensors, systems, and equipment (including weapons).

In closing, I hope it is blatantly obvious that a refuelable UAV can perform an almost unlimited number and variety of missions while providing tremendous capabilities that a manned platform cannot provide. In the future, UAVs will perform electronic intelligence (ELINT), signals intelligence (SIGINT), communications intelligence (COMINT), airborne communications node (ACN) functions, and numerous types of attack missions (i.e., many of the missions currently reserved for manned platforms). Whether its mission is to drop precision guided munitions (PGM) on an unfriendly country on the other side of the world, gather air samples in a nuclear, biological, or chemical (NBC) contaminated environment, or simply to monitor the flow of refugees, the refuelable UAV can perform these missions without the limitations that are inherent when a pilot is onboard. Add the additional air refueling capability and the UAV becomes an effective weapon system, able to perform missions far exceeding the physical limitations of the manned platforms.

The biggest obstacle to overcome now is our personal and institutional prejudices and biases. The technology to build air refuelable UAVs is right at our fingertips and available today. The leadership of the Air Force must be willing to put the "macho" pilot image aside and be "man" enough to replace manned platforms with UAVs in those situations where manned aircraft are not required. Incorporating UAVs into around-the-clock global operations requires the flexibility that only air refueling can provide. The time has come to make this decision and we must be willing to step forward and push for the air refueling receiver that does not complain—the UAV.

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